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NJEM

VOL. 1, NO. 3 JULY - SEPTEMBER, 2000

NIGERIAN JOURNAL OF ENGINEERING MANAGEMENT

Besade Publishing Press

AN EVALUATION OF THE INFLUENCE OF NODES ON THE STRENGTH OF BAMBOO

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ABSTRACT

The structural use of bamboo as a material of construction requires indepth study of the strength properties of the culm in relation to its anatomy. An experiment was therefore conducted to determine whether the presence of nodes on a bamboo culm constitutes a significant weakness to the strength of the culm. Two parallel experiments were conducted using samples without node and samples with node. Test results showed that the average density, compressive stress and modulus of elasticity for specimen without nodes were 1161.18kg/m^3, 66.09 N/mm^2 and 3.18×10^4 N/mm^2 respectively. The corresponding results for specimen with nodes were 1098.69 kg/m^3, 59.4 N/mm^2 and 2.68×10^4 N/mm^2. One way analysis of variance (ANOVA) test showed that there was a significant difference in the mean density and compressive stress of samples without node and samples with node. It was therefore concluded that the presence of node is a significant source of weakness to bamboo culm.

KEYWORDS: Bamboo culm, nodes, properties

INTRODUCTION

Bamboo is a replenishable material indigenous to many developing countries. Its use as a material of construction has not been fully exploited except in some cases where it is used as roof trusses, floor members and reinforcement of mud walls. In the urban areas, the structural applications of bamboo extend to being used as prop for formwork and as scaffolding during rendering and plastering work on construction sites. In all these applications, the use of the culm is based on the rule of thumb and exclude engineering calculations due to dearth of data on the material properties.

Published work on the structural applications of bamboo started to appear in literature to a large extent around mid-twentieth century. Mehta, Uppal and Chadda (1951) investigated the water absorption and volume change of bamboo. Mentzinger and Plourde (1966) carried out tension and bond test on untreated, varnish treated and sealer treated bamboo. Francis and Paul (1966) suggested the procedure for selecting and preparing bamboo as reinforcement. Cox and Geymayer (1969) performed tests to determine the tensile strength, bond strength, coefficient of thermal expansion and flexural strength of bamboo under sustained load. They investigated the properties of bamboo reinforced concrete by varying the type, volume and treatment of bamboo culm. Datyle (1976) identified bamboo structural form which do not depend on bond and can function satisfactorily inspite of poor dimensional stability and low elastic modulus.

Two separate studies on Sulphur-treated bamboo poles (Fang et. al; 1976) and sulphur-treated bamboo rods (Fang and Mehta, 1978) showed that treated bamboos were less sensitive to water absorption than the untreated ones and that non-treated bamboo had light bond with concrete. Janssen (1988) gave some values relating the density of green and dry bamboo to their respective compression, bending and shear stresses for use in the design of bamboo trusses and beams.

Research into the mechanical properties of bambusa vulgaris culm, the most widely available specie of bamboo of structural value in Nigeria had indicated that the presence of node was a potential source of weakness to the strength of the culm (Omojola and Omoyosi, 1976). However this work did not present enough data to show that such reduction in strength is statistically significant. Olateju (1993) investigated the suitability of using bambusa vulgaris splint as reinforcement in terracrete and concluded that the splint was more suitable than the use of the whole culm. Adeyemi and Fagbenle (1999) studied the effect of anatomy and mode of seasoning on the strength properties of bamboo culm. It was concluded that ambient - temperature seasoning was the best mode of seasoning bamboo for improved strength. This work also corroborated the findings of Omojola and Omoyosi that the strength of a bamboo culm tends to reduce due to the presence of node. The object of this experimental work was to determine statistically if the reduction in the strength of bamboo culm as a result of the presence of nodes is statistically significant. The result is expected to provide additional information in the drive towards standardization of bamboo as a material of construction.

INSTRUMENTATION

The tools and equipment employed in this research work were matchets, measuring tape, carpenter's file, protimeter timbernini, weighing scale, electric sawing machine (band saw), 1000KN ELE Compression machine and vernier callipers. The protimeter timbernini was a battery/ac operated hand instrument for determining the approximate moisture content of wood and concrete blockwall. A red light (indicator) on the instrument rises from zero to the required moisture percentage level up to 28%.

MATERIALS AND METHODS

The primary material employed in this work was bambusa vulgaris culm (Figure 1) which is the most widely available specie of bamboo in Nigeria. For the benefit of obtaining a uniform and consistent result, the culms were procured from a single clump within the vicinity of the campus of Obafemi Awolowo University, Ile-Ife. Samples selected for the experimental work were fairly and uniformly tapered culms of reasonable lengths.

A total of 30 fresh culm lengths each nine metres long were cut at a height, 600mm above ground level using matchets. The side branches and other bud-outgrowths were carefully trimmed and transported to the Department of Building Laboratory of the University for processing. Twenty culm lengths were finally selected for the experiment. Flexural tests were eliminated from the design of the experiment because test specimen had to be 600mm to be accommodated by heavy beam flexural testing machine. Nodes on the bamboo culms procured were spaced at approximately 425 ± 25mm interval and hence 600mm specimen without node could not be obtained. Tensile tests were also not included since previous laboratory experiments had indicated that the tensile specimen normally fail in shear parallel to the grains at the tensiometer grips immediately the force is applied and before any recording could take place (Omojola and Omoyosi, 1976; Ukpai, 1988 and Fagbenle, 1990). Only compressive stress was therefore feasible within the objective of this experiment.

The selected 20 culm lengths were divided equally into groups A and B corresponding to where compressive specimen without node and with node were to be taken respectively. The culm lengths in each group were numbered serially from one to ten before cutting started. Each compressive test specimen was 300mm long and were cut serially along each culm length in both groups so that the position of each test specimen above ground level is known. In the case of specimen with nodes, it was ensured that the node occurred at the middle of each specimen. The diagrams of each group of specimen are shown in Figure 2. Twenty test specimens were cut from each culm length and numbered serially from the bottom of the culm length to the tip. Specimens without node were numbered A_{ij} while those with nodes were numbered B_{ij} where:

i is the serial number of culm length
in a particular group
(i = 1,2,3, ---,10).
j is the position of the specimen
along a culm length
(j = 1,2,3,---, 20).

The position of a test specimen above ground level varied from 600mm for j = 1 to 6300mm for j = 20 at an interval of 300mm. A total of 400 specimens (200 specimen per group) were prepared for seasoning under ambient temperature.

The external and internal diameters of each fresh specimen were determined with venires caliper after which they were weighed and their moisture content and density determined. The specimens were then left to dry under room temperature for a period of four months after which they were weighed again and the final moisture content and density determined. All test specimens were seasoned to a moisture content of 12 ± 0.15% on dry basis.

The specimen in each group were carefully subjected to compression load one after the other using 1000KN ELE compression machine. Each sample was positioned such

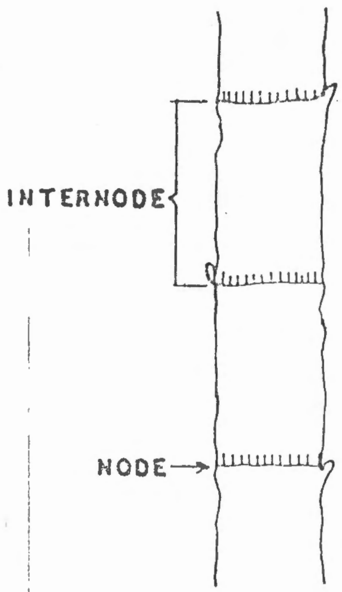

Fig. 1: Bamboo Culm

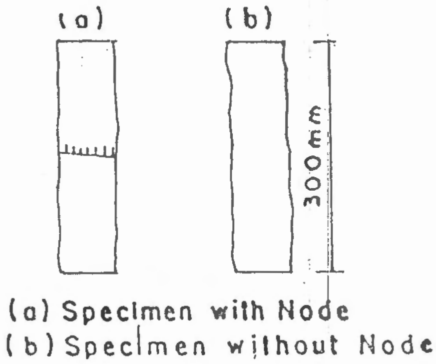

Fig. 2: Samples for Compression Test

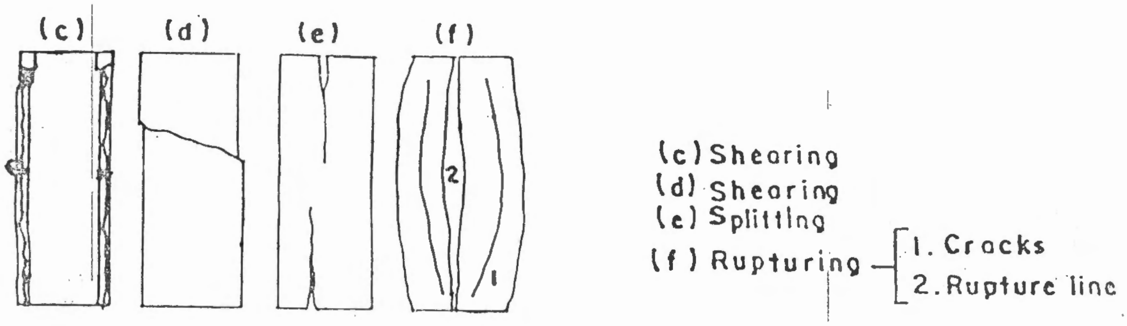

Fig. 3: Modes of Bamboo Failure under Compression

that the bottom part rests on the bottom platen of the machine while the top platen fixed the specimen in upright position. This ensured that compression stress was evenly distributed parallel to the grain of the specimen. A specimen was loaded by clockwise tightening of the loading valve. The black pointer on the scale then carried along with it the red pointer at the point the specimen started to experience compressive stress. Immediately the material failed, the black pointer moved back to the zero point leaving the red pointer to be read off.

The modulus of elasticity in compression was obtained by dividing the product of the load at failure and the gauge length by the product of the cross-sectional area and the axial shortening.

$$E = PL/A\Delta \qquad \ldots(1)$$

where,

E is the modulus of elasticity

L is the length of the test specimen A is the cross-sectional area

Δ is the axial shortening.

Analysis of variance (ANOVA) test was performed to know whether the differences among the sample means of the density and that of the compressive strength for specimen with node and specimen without node were significant. Two similar null hypotheses were thus formulated as follows:

(1) There is no difference in the sample means (U_d) of the density of specimen with node and specimen without node.

H_o: $U_{d1} = U_{d2}$

H_1: $U_{d1} \neq U_{d2}$

(2) There is no difference in the sample mean (U_c) of the compressive stress of specimen with node and specimen without node.

H_o: $U_{c1} = U_{c2}$

H_1: $U_{c1} \neq U_{c2}$

Level of significance: = 0.05

Criterion: Reject the null hypothesis if $F > F_{0.05} = 4.12$ in the two cases, for K-1 = 1 and N-K = 38 degrees of freedom; otherwise, accept it.

RESULTS AND DISCUSSION

The average green density, compressive stress, and modulus of elasticity for the 200 specimen tested under groups A and B are shown in Tables 1 and 2 respectively.

Table 1: Average Density, Compressive Stress and Modulus of Elasticity of Bamboo Specimen without Node

HAG*	GD*	CS*	ME*
600	1242.38	75.46	4.37
900	1240.11	74.43	4.13
1200	1212.45	72.17	3.96
1500	1201.14	71.05	3.85
1800	1199.08	70.09	3.77
2100	1191.19	69.99	3.64
2400	1189.05	69.25	3.44
2700	1184.44	67.99	3.31
3000	1175.47	67.93	3.27
3300	1169.18	67.15	3.19
3600	1160.18	67.00	3.08
3900	1155.53	65.81	2.99
4200	1147.77	64.17	2.92
4500	1141.46	62.18	2.77
4800	1138.85	62.08	2.71
5100	1134.23	61.16	2.66
5400	1121.28	60.88	2.65
5700	1119.29	58.15	2.43
6000	1111.44	57.86	2.41
6300	989.07	57.01	2.38
$\bar{X}$	1161.18	66.09	3.20

Source: Experimental Result

* HAG – Height Above Ground (mm)
GD – Green Density (Kg/m^3)
CS -- Compressive Stress (N/mm^2)
ME – Modulus of Elasticity x 10^4 (N/mm^2)

The tables showed that the density and strength properties of bamboo decreased along the length of the culm from the bottom to the tip. The variation of the density for the specimen without node was 1242.38kg/m^3 at 600mm above ground level to 989.07kg/m^3 at 6300mm above ground level. For the specimen with node the corresponding variation of density was 1195.24kg/m^3 at the bottom to 799.59kg/m^3 at the tip. The average density for the specimen without node was 1161.18kg/m^3 and 1098.69kg/m^3 for the specimen with node. The presence of node therefore decreased the density of bamboo culm.

In the compression test, the failure of the specimen was either by shearing, splitting, rupturing or a combination of these (Figure 3). The compressive stress for the specimen without node decreased from

75.46N/mm^2 at the bottom to 57.01N/mm^2 at the tip. The variation of the compressive stress for specimen with node was 68.94 N/mm^2 at the bottom to 35.84N/mm^2 at the tip. The average compressive stress was 66.09N/mm^2 for specimen without node and 59.41N/mm^2 for specimen with node. The presence of node on a bamboo culm therefore, is a source of weakness to the bamboo. The results of the modulus of elasticity showed similar reducing trend from the bottom of the culm to the tip. For specimen without node, the modulus of elasticity varied from 4.37×10^4 N/mm^2 to $2.38\ \times10^4$N/mm^2. The corresponding variation for specimen with node was 3.38×10^4N/mm^2 at the bottom to 2.20×10^4N/mm^2 at the tip. The average modulus of elasticity for specimen without node was $3.20\ \times10^{4}$ N/mm^2 and $2.75\ \times10^4$ N/mm^2 for specimen with node

Table 2: Average Density, Compressive Stress and Modulus of Elasticity of Bamboo Specimen with Node

HAG*	GD*	CS*	ME*
600	1195.24	[illegible]	3.38
900	1194.11	[illegible]	3.29
1200	1191.07	[illegible]	3.21
1500	1189.04	[illegible]	3.05
1800	1188.17	[illegible]	2.99
2100	1184.25	[illegible]	2.90
2400	1175.42	[illegible]	2.84
2700	1168.92	[illegible]	2.83
3000	1152.44	[illegible]	2.81
3300	1144.48	[illegible]	2.25
3600	1111.22	[illegible]	2.69
3900	1108.47	[illegible]	2.65
4200	1105.65	[illegible]	2.61
4500	1103.64	[illegible]	2.60
4800	1101.55	[illegible]	2.57
5100	1080.24	[illegible]	2.53
5400	985.11	[illegible]	2.44
5700	972.43	[illegible]	2.41
6000	822.73	[illegible]	2.32
6300	799.59	[illegible]	2.20
X	1098.69	[illegible]	2.75

Source: Experimental Analysis.

* HAG -- Height Above Ground (mm)
GD -- Green Density (Kg/m^3)
CS -- Compressive Stress (N/mm^2)
ME -- Modulus of Elasticity x 10^4 (N/mm^2)

The results of the ANOVA tests for the density and the compressive stress are shown in Tables 3 and 4 respectively.

Table 3: ANOVA Test Result for Variation in Density

Source of Variation	Degrees of Freedom	Sum of Square	Mean Square	F
Experiment	1	39032.50	39032.50	4.64
Error	38	319580.09	8410.00	
Variation	39	358612.59		

Source: Experimental Analysis

Table 4: ANOVA Test Result for Variation in Compressive Stress

Source of Variation	Degrees of Freedom	Sum of Square	Mean Square	F
Experiment	1	445.02	445.02	7.04
Error	38	2401.10	63.19	
Variation	39	2846.12		

Source: Experimental Analysis

Table 3 showed that $F = 4.64 > F_{0.05} = 4.12$. Hence the first null hypothesis was rejected and it was concluded that the presence of a node contribute significantly to the reduction in density of a bamboo culm. Also from Table 4, $F = 7.04 > F_{0.05} = 4.12$ and similarly, the second null hypothesis was rejected and it was concluded that the presence of a node contribute significantly to the weakness of a bamboo culm. It appeared that result obtained from samples with node are more realistic for use in design since bamboo structural members will in reality contain a number of nodes.

CONCLUSION

The experimental work revealed that:

1. The density and strength properties of bamboo decreased from the bottom of the culm to the tip.

2. The presence of nodes reduced the density and compressive strength of bamboo culm significantly.

3. Data obtained from samples with node were more realistic for use in practical structural design with bamboo.

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